Mining Science and Technology (China) 21 (2011) 709–713

Contents lists available at SciVerse ScienceDirect

Mining Science and Technology (China)

journal homepage: www.elsevier.com/locate/mstc

Variation in the temperature field of rocks overlying a high-temperature cavity during underground coal gasification

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ARTICLE INFO

Article history:
Received 11 January 2011
Received in revised form 15 February 2011
Accepted 13 March 2011
Available online 8 November 2011

Keywords:
Stratum
Thermal conductivity
Temperature
Simulation

ABSTRACT

High temperature affects rocks in a way that changes the physical and mechanical properties of them. The temperature field in rock overlying a high temperature zone has been estimated using experimental research on thermal conductivity of the overlying strata. Numerical analysis software was used to estimate rock thermal conductivity at different temperatures. These estimates were then used with COMSOL Multiphysics to perform a numerical analysis with the heat conduction model. The results show that rock thermal conductivity decreases as the temperature increases and that various lithologies show similar behavior. The thermal conductivity of each rock type differs from the others at a given temperature. Exact values for the temperature distribution in the overlying strata during the process of underground coal gasification are obtained from the numerical simulation. The temperature in the rock changes with the height and direction from the gasifier. Temperature gradients vary for different types of rock. This result provides an important reference for further study of the strength of overlying strata subject to the process of underground coal gasification.

1. Introduction

The famous Russian chemist Dmitri Mendeleev first proposed the idea of underground coal gasification in 1888. He suggested that, "the purpose of coal mining is the extraction of the energetic composition in coal, rather than the coal mining itself." The essence of the idea is just extracting the energy by changing physically solid coal into chemicals that might be removed without mining. This technology is has good qualities including safety, lower investment costs, higher efficiency, and less contamination of the environment. It is praised as the second generation of mining methods.

Since the 1930's the United States, Germany, the former Soviet Union, and other major coal-producing countries have been energetically committed to research on this technology. They have made a great deal of progress and have developed some key technologies for underground coal gasification. Since 1958 China has been conducting experiments on underground coal gasification under natural conditions. But the expansion of the combustion space during the gasification process causes the overlying strata to break down, which directly affects quality and safety during gas production. However, rock collapse in the gasification stope is different form collapse at room temperature because of the fact that the mechanical properties of the rock change under the influence of temperature. All studies on the variation in the temperature field during high-temperature combustion have significant practical meaning for this reason [1–6].

Current work at home and abroad on the mechanical properties of sandstone and granite at high temperatures has developed a collection of data. But research on the temperature field, especially in the stratum rocks at high temperature, is quite limited.

The work described here takes a coal seam mudstone appropriate for Inner Mongolia as representative. Various samples from these strata are tested for thermal conductivity at elevated temperatures using a DRX-II instrument. An equation describing each high-temperature parameter as a function of the changing temperature was developed. Numerical simulation was used to analyze the distribution of a stable temperature field in the overburden during the process of underground coal gasification. This analysis provides reference for further study on rules of the stress field, the displacement, and heat migration. Safe and effective underground gasification is aided by this understanding [7–11].

2. Rock thermal conductivity

2.1. Sample preparation

A rock core longer than 150 mm was selected and the exterior of the core was verified to be free from defects such as cracks,

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1674-5264/$ - see front matter © 2011 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
doi:10.1016/j.mstc.2011.03.005

deformation, karst, or uneven distribution of stomata. The core was cut to a 150 mm diameter cylinder that was cut into two pieces along the cylindrical axis. The two pieces are put together without any voids.

In this experiment lithologies like roof siltstone, roof sandstone, floor sandy mudstone, roof mudstone, roof gritstone, or roof sandy mudstone were chosen as samples. Three pieces of each lithology were used to carry out the experiments.

2.2. Experimental device and process

A DRX-II coefficient of thermal conductivity measurement system, and the related control system and various accessories like a hot wire, were used during the tests. Fig. 1 shows the main test instruments.

During testing the experimental protocol and procedures set in advance were followed. Samples were dried at constant temperature (100 °C) for two hours before testing to avoid moisture interference. The condition for a stable temperature was that the temperature drifts over 10 min was no more than 0.2 °C. This guarantees that samples have the required temperature during the test and that the figures from the experiment are reliable.

The first step of the test is to heat the sample to the desired test temperature (50, 100, 200, 300, 400, 500, 600, 700, 800, 900, or 1000 °C). Then the computer automated measuring, and data reduction, system was used to find the coefficient of thermal conductivity of the rock.

2.3. Results and discussion

The experimental results are tabulated in Table 1.

For all the rocks with the various lithologies the coefficient of thermal conductivity, over all the different temperatures, varies from 0.693 W/(m K) to 1.412 W/(m K).

For all the rocks the coefficient of thermal conductivity decreases with increasing temperature. Fig. 2 shows the variation in coefficient of thermal conductivity at different temperatures.

3. Numerical simulation of the temperature distribution in the overlying strata

Numerical analysis has been extensively applied to various practical engineering technology issues including heat transfer. Numerical analysis is superior for situations where the model is geometrically complex, boundary conditions change with time, or the physical properties change over time [12–14].

COMSOL Multiphysics is an advanced numerical simulation software package suitable for simulating all kinds of physical processes in science and engineering. Using it to solve multi-field problems amounts to solving equations: Users need only to choose, or define, different partial differential equations and combine them in arbitrary ways. Then the direct coupling analysis of a multi-physical field may easily be realized. The completely open structure allows users to freely define the required partial differential equations in a graphic interface and to explore the parameters under arbitrary and independent control. The material properties, boundary conditions, and load all support parameter control [15,16].

The COMSOL Heat Transfer Module was used to numerically simulate the overlying strata temperature field during coal gasification to obtain the temperature gradient in the overlying strata.

3.1. Theoretical basis for the heat conduction calculations

Fourier's law gives the relationship between the flux in a heat conductor and the associated temperature gradient. Conservation of energy links the changing temperature and heat conducted over space and time. Given that a micro-body conserves energy in unit time the differential equation for thermal conduction in a rectangular coordinate system is given by:

$$\frac{\partial}{\partial x}\left(\lambda_x \frac{\partial t}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_y \frac{\partial t}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda_z \frac{\partial t}{\partial z}\right) + q = \rho c \frac{\partial t}{\partial \tau}$$

This differential equation represents the variable thermal conductivity heat conduction problem. For engineering problems the thermal conductivity is taken to be isotropic. The process for numerical calculation is outlined in Fig. 3.

3.2. Computational model

Rock soil is a poor conductor of heat so the temperature in the overlying strata changes mainly in area of the high-temperature gasifier. Experience has shown that the size of the model is satisfactory for a plane model 240 m by 20 m with a boundary condition of 20 °C for the surrounding temperature [17,18].

3.3. Model grid

The mesh generation was done with a program. There were 3302 grid points, 6511 triangle units, and 1574 boundary units. The mesh is shown in Fig. 4 where X in the horizontal direction represents rock length and Y in the vertical direction represents stone height: The units are meters.

Fig. 1. DRX-II coefficient of thermal conductivity measurement equipment and the test control system.